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REDUCING NOISE EXPOSURES PRODUCED BY VIBRATORY FINISHING MACHINES

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By:

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ABSTRACT

Tumbling operators are exposed to loud occupational noises when loading and unloading the metal products in tumbling machines. The increase in the number of hearing loss injuries in the metal stamping industry initiated OSHA's Special Emphasis Programs in designated industries and locations across the United States. Because occupational hearing loss injuries do not manifest themselves until years later, it is critical that employers install engineering controls immediately in order to protect worker's hearing and prevent hearing loss injuries.

Tumbling machines come in a variety of configurations. In addition to sound absorption material that can be installed on floors, ceilings, and walls, noise covers can also be custom-made and installed on tumbling machines. This study analyzed the effectiveness of custom-made tumbling noise covers in reducing the sound levels generated from the tumbling machines and reducing the operator's noise exposures. Noise measurements and personal noise exposure were obtained prior to the installation of the noise cover and after the installation of the noise cover.

The sound level and noise exposure results indicate that the noise cover is an effective control in reducing the sound levels produced by the tumbling machine and reducing noise exposures for the tumbling operators. Sound levels and operator's noise exposures can be further reduced through the combination of machine configuration, hearing protection, use of absorption material to cover the walls, ceilings, and floors, enclosing the machines in a separate room, and the use of noise covers over the tumbling machines.

ACKNOWLEDGMENTS

I would like to express my gratitude to the Industrial Hygiene professors at Montana Tech for effectively teaching their classes online throughout the distance IH Master's program. Every single professor taught their class with sincere passion for the subject and for workplace health and safety. I will miss learning and collaborating with the IH professors at Montana Tech.

I would like to thank my husband for supporting me and encouraging me while writing my report, especially on the days that I was exhausted and just wanted to play with our daughter. My daughter, even at the age of one, motivated me to write the report. Her smiles and squints are the reasons I would persevere to obtain my Master's.

Last but not least, I want to thank my parents and my brother. Their help with watching my daughter meant so much, and I would not have accomplished as much as I have without their love and support.

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Acronyms

ACGIH	American Conference of Governmental Industrial Hygienists
AIHA	American Industrial Hygiene Association
dB	decibel
dBA	decibel measured using A frequency-weighting (also see L_A)
HCP	Hearing Conservation Program
HCD	Hearing Conservation Device
NAICS	North American Industrial Classification System
NIHL	Noise Induced Hearing Loss
NIOSH	National Institute of Occupational Safety and Health
NRR	Noise Reduction Rating
OSHA	Occupational Safety and Health Administration
PEL	Permissible Exposure Limit
PPE	Personal Protective Equipment
REL	Recommended Exposure Limit
TLV	Threshold Limit Value
TWA	Time-Weighted Average

I. Introduction

Metal stamping shops vary in size from as few as three employees and running one stamping press to big shops with hundreds of employees and more than twenty five stamping presses. Regardless of the size of the stamping shop, all of these stamping shops face the same obstacle after a coil of metal is pressed and formed into a stamped product. The pressed metal product will have sharp edges or ridges called burrs that need to be removed and smoothed so the metal product can meet customer specifications and be safe to use as a final end product. Furthermore, after the stamping process, the metal products need polishing and descaling to improve the appearance of the final product.

To remove the burrs and polish the parts, metal stamping shops process the parts in vibratory finishing machines. These machines can also be called tumbling machines, tumblers, or mass finishing machines. Tumbling machines can vary in configuration. For the purpose of this report, round bowl vibratory finishing machines will be investigated. Tumbling machines vibrate the metal products together in a vibratory bowl that is filled with media such as corncob, ceramic rocks, and plastic, depending on the desired finished. The metal products tumble against one another, tumble against the media, and a cleaning compound is metered in with water so the end result is a smooth, uniform, and polished finished product.

Metal stamping companies chose tumblers to deburr and polish their parts because large quantities of parts can be processed together at one time in one tumbling machine. The parts, media, and diluted soap are all contained together in a vibratory bowl constructed of steel and lined with polyurethane. The mechanics of how the tumbling machine operates will be further discussed in this paper.

The tumbling process is a loud operation that often results in sound levels that far exceed the OSHA and ACGIH exposure limits. Employees that operate this tumbling process often wear hearing protection, such as, ear plugs or ear muffs and participate in a hearing conservation program. Some tumbling machines have sound covers that come manufactured and installed with the tumbling machine. However, most tumbling machines are open-topped and shop owners typically rely just on personal protective equipment as the only option for controlling the noise exposure levels for their workers. No studies have been published on sound levels generated from vibratory finishing machines in the manufacturing industry. Gillespie (2007) mentions that various options for noise reduction exist, but some options may interfere with production and maintenance operations, although they may absorb the sound well. Gillespie did not evaluate the effectiveness of such noise controls.

The purpose of this study was to evaluate the methods to reduce sound levels generated from operating the tumbling machines and to reduce noise exposure levels for operators of the tumbling machines. Noise induced hearing losses caused by occupational exposures are incurable but preventable. When an employee endures an occupational noise induced hearing loss, their quality of life is diminished by an extent, and the effects can also impact the employee’s family and friends.

This study addressed the different control methods to reduce tumbling machine noise, and how the controls differ in both costs and effectiveness. It specifically investigated the effectiveness of sound covers for reducing the sound levels and noise exposures for tumbling operators. The following hypothesis was developed to determine if the noise cover is effective in reducing the noise exposure levels for operators.

Null Hypothesis (H_0): There will not be a significant difference ($p \geq 0.05$) in sound pressure levels prior to the installation of the noise cover compared with the sound pressure levels measured after the installation of the noise cover

Alternative Hypothesis (H_1): There will be a significant difference ($p < 0.05$) in sound pressure levels prior to the installation of the noise cover compared with the sound pressure levels measured after the installation of the noise cover

II. Background

A. The emergence of occupational noise induced hearing loss

Awareness of the danger of loud occupational noises and its effect on worker's hearing predates back to the Middle Ages. Workers such as blacksmiths, miners, and church ringers reported hearing problems that were associated with their job positions. The first medical journal detailing the relationship between "blacksmiths deafness" and ringing in the ears was referenced in a medical document in early 1830's (Berger, Royster, Royster, Driscoll, & Layne, 2003). Fifty years later, "boiler-makers" deafness was documented in a separate medical journal. Loud occupational noises were considered part of the job at the time for the miners, blacksmiths, and boilermakers. Some workers tried various controls, such as, placing cotton wool and cotton pads in their ears to reduce the noise exposure; however, such controls were ineffective, and the workers didn't have any other alternatives (Berger et al., 2003).

Hearing conservation gained notoriety due in part to World War II (1940-1945) and the Korean War (1950-1953). Many soldiers returned home from their service with permanent hearing loss. Furthermore, industries that produced items and weapons for WWII, such as, the metal, shipbuilding, and aviation industries were on over-drive production to keep up with the war demands. The hectic production schedules resulted in many workers filing hearing loss claims due to the noisy around the clock operations. Hearing conservation programs started to develop in the late 1940s, and legislation for control of noise exposures emerged to prevent more noise induced hearing loss injuries (Berger et al., 2003).

B. How humans hear (ear anatomy and physiology)

Sound is nearly everywhere, and humans are able to communicate with one another effectively using verbal communication in the use of sounds. How humans hear is a complex system involving various anatomical features and physiological mechanisms. Hearing loss can vary significantly depending on the source, exposure, anatomical and physiological mechanisms affected. To fully understand the different categories of hearing loss, one first has to understand the different anatomical and physiological features of the ear and how sound travels to the brain to be interpreted as sound. The following paragraphs will briefly describe the different components of the ear and what sound is doing in each component.

The ear has three main components: the outer ear, the middle ear, and the inner ear. The main anatomical features that make up the outer ear are the "external ear" (called the pinna), the ear canal (called the external auditory canal), and the eardrum (called the tympanic membrane). The outer ear is responsible for collecting the sound and modifying the acoustic wave of the sound before it hits the eardrum. The ear canal can modify the acoustic wave and amplify sounds that travel to the eardrum by 10 to 15 decibels in the 2 – 4 kHz sound region (Berger, Royster, Royster, Driscoll, & Layne, 2003).

The middle ear is comprised of small bones (malleus, incus, and stapes), muscles (tensor tympani and stapedius), and the Eustachian tube. The middle ear is responsible for taking the vibrations generated by the eardrum and transferring and amplifying those vibrations to the small bones of the middle ear to the entrance of the inner ear by the action of the stapes bone (Berger et al., 2003). The stapes bone moves with a piston like action which sends vibration and pressure into a structure called the bony labyrinth, of the inner ear. The Eustachian tube is a separate channel that is connected to the nasal air passages. The Eustachian tube is important for maintaining the pressure within the middle ear equal to the pressure of the outside atmosphere by means of a valve that opens when a person swallows.

The inner ear is the most complex, comprised of many anatomical parts within the inner ear. For the purpose of this study, we will focus on the following anatomical features of the inner ear: sensory receptors (inner hair cells and outer hair cells), cochlea, vestibule, semicircular canals, cochlear duct, perilymphtic space, round window, basilar membrane, scala of vestibule, and scala of tympani. The bony labyrinth is filled with a fluid like substance called perilymph. The round window allows displaces the fluid when the stapes pulses on the labyrinth allowing vibration to enter and travel through the labyrinth. Vibrations produced by the stapes and into the labyrinth are drawn into the cochlea (snail like shaped organ). The scala of vestibule and scala of tympani allow the vibrations to travel up or down the cochlea. The deflection of the basilar membrane located between the scala of vestibule and scala of tympani results in bending of the hair cells and initiation of nerve impulses. These impulses are then carried by the auditory nerve and processed by the brain giving rise to the perception of sound (Berger et al., 2003). Figure 1 depicts an illustration of how sound enters the three different sections of the ear and the main anatomical parts located within the different sections.

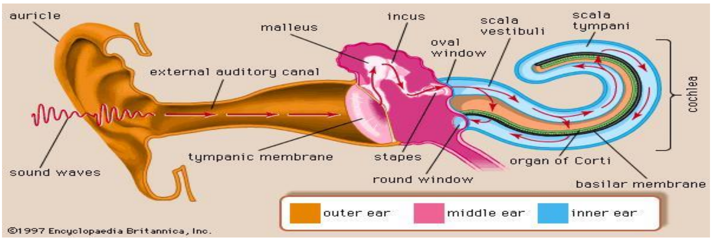

Figure 1 – How Sound Moves through the Ear with Anatomical Features
(Ear: hearing mechanism, 1997)

C. Hearing Loss

Hearing loss has numerous causes. A person may be born with reduced hearing or develop hearing loss due to genetic reasons or illnesses, nosoacusis. Everyone also experiences hearing loss with age, called presbycusis. Furthermore, someone may experience temporary or permanent hearing loss caused by noise exposures outside the work environment, such as listening to loud music or using chain saws and lawn mowers for long periods of time without using hearing protection. Such hearing loss is sociacusis.

The types of hearing loss of interest in this study, conductive and sensorineural, are caused by occupational noise exposures. Conductive hearing loss occurs when the transmission of sound from either the external or middle ear are damaged which then interferes with the transmission of sound to the inner ear. Conductive hearing loss can happen as the result of an accident at the workplace, such as a rupture or penetration of the eardrum but occurs more frequently when wax blocks the auditory canal, fluid is present in the middle ear, or there is blockage in the Eustachian tube, which are usually non-occupational. Conductive hearing loss is typically reversible through medical treatment (United States Occupational Safety and Health Administration, 1990).

Conversely, sensorineural hearing loss is usually irreversible and commonly occurs from occupational noise exposures. Sensorineural hearing loss occurs when the hair cells, sensory cells of the organ of Corti, and the nerve endings for the auditory nerve are damaged permanently. Unfortunately, sensorineural hearing loss is usually not detected immediately, and noticeable symptoms may not occur for 5-20 years, depending on the severity of the noise exposure. Some sensorineural hearing losses can be temporary, if a worker does not have further exposures (United States Occupational Safety and Health Administration, 1990).

D. Regulatory history

Air Force Regulation 160-3 was one of the first hearing conservation regulations published in October of 1948 by the Department of Air Force. The regulation mandated "hearing protection be worn by personnel working in high-level noise, noise measurements be performed to determine degree of risk, exposure periods be minimized, and audiometric monitoring be performed on people engaged in testing and operating turbojet and rocket engines" (Humes, 2005, p. 150). Industrial hearing conservation programs also started to emerge in the late 1940's and early 1950's. The government, specifically the Department of Labor (DOL), started issuing noise and hearing regulations in the 1960's when the Occupational Noise Exposure Standard was added as an amendment to the Walsh-Healey Public Contract Act. The Noise Exposure Standard set in 1969 was based on the American Conference of Governmental Industrial Hygienists (ACGIH) noise exposure limits. The threshold limit value (TLV) was set at 90 dBA for an 8-hour Time-Weighted Average level (TWA) with a 5-dBA exchange rate. This standard affected companies that had contracts with the federal government. The U.S. Occupational Safety and Health Administration (OSHA) adopted the Noise Exposure Standard, along with many other standards when OSHA was created in 1970. OSHA still uses the noise exposure Permissible Exposure Limit (PEL) of 90 dBA for an 8-hour TWA, with an exchange rate of 5 dB and an action limit of 85 dBA.

The National Institute of Occupational Safety and Health (NIOSH) established noise standards in 1972 in their published noise document called *Criteria for a Recommended Standard: Occupational Exposure to Noise*. NIOSH's recommended exposure limit (REL) was set at 85 dBA for an 8-hour Time-Weighted Average (TWA) with an exchange rate of 3 dB. Furthermore, the American Conference of Governmental Industrial Hygienists (ACGIH) Threshold Limit Value (TLV) was 90 dBA for an 8-hour Time-Weighted Average (TWA) with an exchange rate of 5 dB until 1976, when they lowered the TLV to 85 dBA and lowered the exchange rate to 3 dB. NIOSH and ACGIH had more stringent noise exposure values compared to OSHA. NIOSH recommended that OSHA lower their PEL to 85 dBA in their 1972 Criteria Document. OSHA investigated NIOSH's recommendation of lowering the PEL by holding multiply meetings involving safety and regulatory professionals, invited public comments and suggestions, and created multiple drafts. About 10 years after the initial NIOSH recommendation for OSHA to lower the PEL, OSHA declared to keep the PEL at 90 dBA for an 8-hour Time-Weighted Average, with an exchange rate of 5 dB. However, OSHA stated that engineering control and administrative controls should be the first lines of protection for worker's noise exposures. In order to show some consensus with the 85 dBA recommended 8 hour time-weighted average, OSHA created the action level and set it at 85 dBA. Table 1 depicts the differences in the noise standards among the various governmental agencies and non-governmental advisory groups.

Table 1: Comparison of Noise Standards

Standard	**OSHA Hearing Conservation (HC)**	**OSHA Permissible Exposure Limit (PEL)**	**ACGIH Threshold Limit Values (TLV)**	**NIOSH Recommended Exposure Limit (REL)**
Exchange Rate	5 dB	5 dB	3 dB	3 dB
Time Weighting	Slow	Slow	Slow	Slow
Frequency Rating	dB(A)	dB(A)	dB(A)	dB(A)
Threshold	80 dB	90 dB	80 dB	80 dB
Criterion Time	8 hrs	8 hrs	8 hrs	8 hrs
Criterion Level	90 dB	90 dB	85 dB	85 dB

The OSHA PEL lowering debate initiated the Hearing Conservation Amendment (HCA), published in 1981 and issued in 1983. The Hearing Conservation Amendment required employers to create and implement hearing conservation programs for every employee who is exposed to Time-Weighted Averages equal to or exceeding 85 dBA , which is the action level. Per the HCA, employers have the responsibility to:

- monitor the noise exposures of workers at least once per year;
- provide baseline audiograms within the first 6 months of an employee's exposure to 85 dBA or greater;
- arrange annual audiograms every subsequent year, and worker's whose audiograms results indicate a "standard threshold shift require further action by the employer, and
- provide hearing protection devices (HPD's) at no costs to all employees, and include training on HPDs, along with more in-depth training on noise .

OSHA's noise standards and the Hearing Conservation Amendment requirements have not changed since their inception. Some companies are not aware of the hazards of noise, or that they may be exposing their workers to damaging noise levels. Usually the dangers of occupational noise exposure comes to an employer's attention when workers file worker compensation claims, or when OSHA enters the facility for an inspection either unannounced or due to a complaint. If an industry, such as, metal stamping has a high number of reported hearing injuries, or the industrial work occurring results in a higher risk of damaging the worker's health, then OSHA can implement Local Emphasis Programs (LEPs), Regional Emphasis Programs (REPs), and National Emphasis Programs (NEPs). These emphasis programs are designed to make employers in the appropriate areas aware of the emphasis program, as well as, the hazards that the program is designed to reduce or eliminate. In 2015, OSHA reported there were four Regional Emphasis Programs and one Local Emphasis Program established affecting a total of 25 states to issue inspections and bring about awareness about the hazards of noise to selected industries (Local Emphasis Programs, n.d).

E. Metal Stamping Industry

The size and growth of the metal stamping industry and mass finishing industry will be influenced by the economic supply and demand for products that are made out of metal parts, such as cars, metal medical parts, and aerospace parts. If the industries grow and hire more workers, then more employees may be exposed to loud noises through the tumbling operation and could suffer a hearing loss injury.

1. Industry Size and Growth

Tumbling machines are used after the metal stamping process. While tumbling and metal stamping go hand and hand, metal stamping is the primary industrial activity and tumbling is the secondary industrial activity occurring at facilities. The North American Industry Classification System (NAICS) code for these facilities is metal stamping (2007 NAICS 332116, 2012 NAICS 332119). Some companies do only tumbling for their metal stamping customers, which is a different NAICS code of “other manufacturing” (NAICS 333298, 2012 NAICS 333249). Note that the NAICS codes changed in 2012, and it is possible that not all of the employers updated their industry codes, which would affect the number of employees reported.

According to data obtained from the United States Census Bureau, employment in the metal stamping industry and other manufacturing industry was on a steady incline from 2003 to early 2008. However, the automotive industry plummeted in late 2008, which caused a recession for all industries that manufactured or provided services for the automobile industry, including metal stamping and tumbling. From 2009 to early 2012, the manufacturing industry laid off employees, which is depicted in Figure 2.

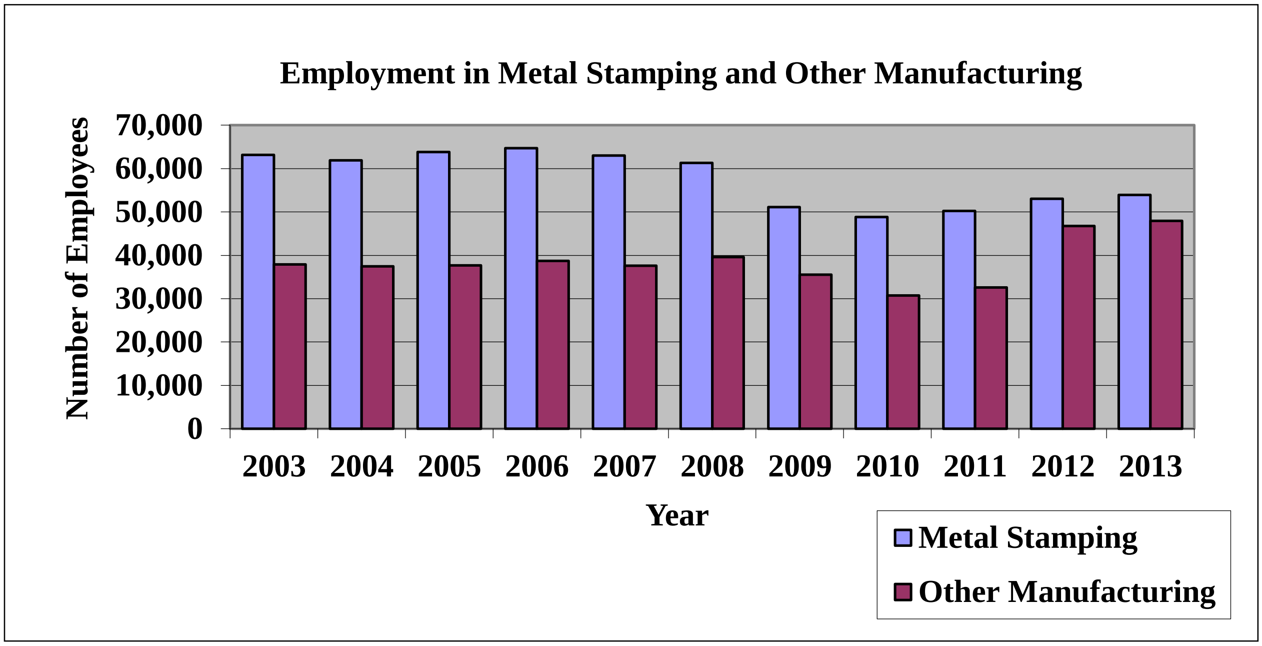

Figure 2 – Employment in the Metal Stamping and Other Manufacturing Industries. Adapted from http://www.census.gov/econ/susb/historical_data.html. Copyright 2016 by United States Census Bureau. Reprinted with permission

The automotive industry started to improve in late 2012, and the affecting industries also started to improve and started hiring workers. Metal stamping and other manufacturing industries are back on a steady incline, and it is projected that their employment numbers will be back to pre-recession in a few years' time.

The employment figures are important to support the mission to decrease noise exposures. Even at the lowest employment year, 48,000 employees in metal stamping, and

30,000 employees in “other manufacturing” may have been exposed to occupational noises that could have resulted in noise induced hearing loss injuries.

2. Hearing Loss Injuries

The United Sizes Bureau of Labor Statistics (BLS) releases data on occupational injuries and illnesses for all industries every year. The “Survey of Occupational Injuries and Illness” is not a required reporting program for employers. Instead, the survey program takes a collection of employer’s reports, approximately 176,000, from private industries in order to provide a summary of the injury and illnesses for the year. Annual injury and illness reports can be retrieved for any industry, and the reports can be filtered by injury type; i.e., hearing loss, skin, respiratory, etc. The number of hearing loss injuries, total injuries, and the incident rates for the metal stamping industry were obtained. The incidence rate and the number of hearing loss injuries for “other manufacturing” industry, were too low to be reported.

In 2014, there were approximately 200 cases of hearing loss injuries reported, which is higher than 2013 through 2010. There were approximately 100 cases of hearing loss reported every year for the metal stamping industry from 2010 to 2013, which is a decline from previous reporting years before 2010. However, since the number of hearing losses injuries went up in 2014 and was constant for three consecutive years, when one would suspect to see a decline of the number of employees suffering noise inducted hearing loss, this supports the claim that noise exposures are still occurring too frequently, and further action is required. Therefore, Figure 3 depicts the hearing loss cases in metal stamping compared to the total number of injuries reported for metal stamping.

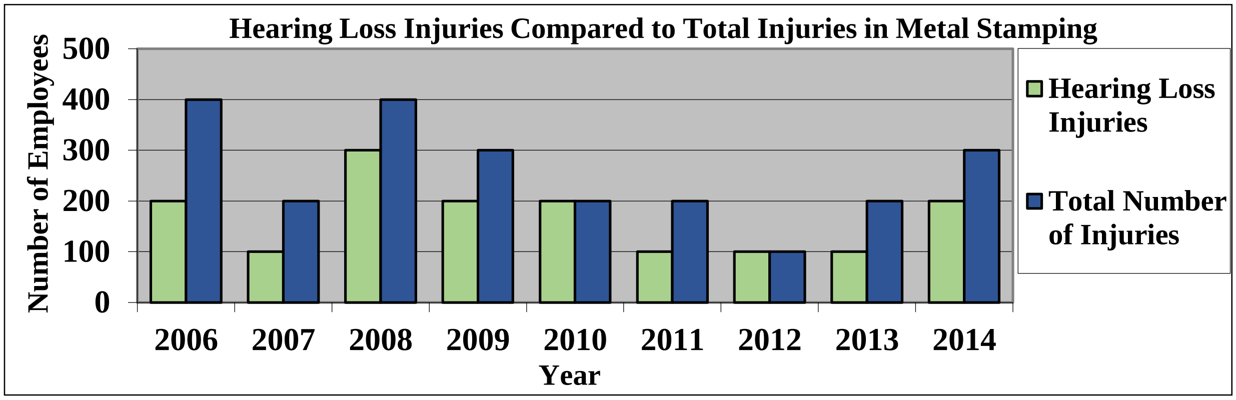

Figure 3 – Hearing Loss Injuries in Metal Stamping Industry (NAICS 332119). Adapted from http://www.bls.gov/iif/oshsum.htm . Copyright 2015 by Bureau of Labor Statistics. Reprinted with permission

The injury data reported is not that specific. It only reports to the nearest hundred; therefore, the hearing loss injuries may be equal to the total number of injuries reported, even though, there may be a difference in tens or ones of cases.

The incidence rates for hearing loss injuries and total injuries for metal stamping were also obtained from the Bureau of Labor Statistics (BLS). The incidence rate is calculated from equation 1,

$$(N/EH) \times 20{,}000{,}000 \quad (1)$$

where N represents the number of illnesses, EH is the total hours worker by all employees during the calendar year, and 20,000,000 is the base for 10,000 equivalent full-time workers working 40 hours per week, 50 weeks per year. The incidence rate for hearing loss injuries and the incidence rate for total cases is per 10,000 full-time workers. As Figure 4 displays, the incidence rate for number of hearing loss injuries increased since 2012, and the incidence rate for hearing loss injuries makes up a higher percentage of the total injuries incidence rate.

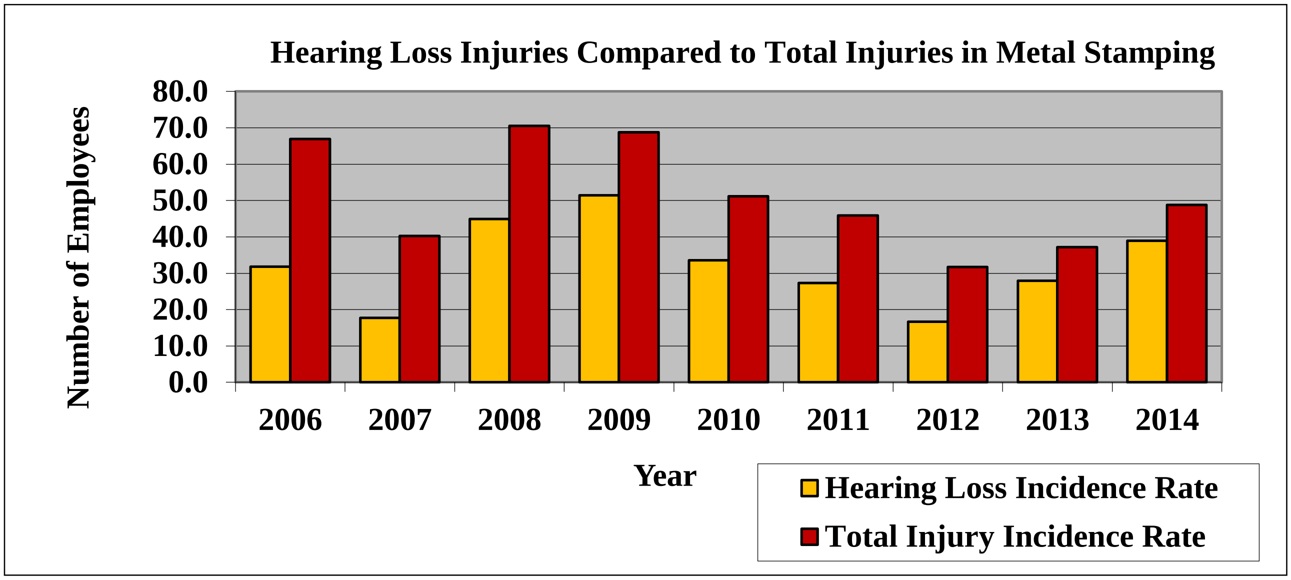

Figure 4 – Incidence rates per 10,000 workers for hearing loss injuries and total injuries. Adapted from http://www.bls.gov/iif/oshsum.htm . Copyright 2015 by Bureau of Labor Statistics. Reprinted with permission

In 2014, it was reported that 48.8 workers out of 10,000 workers suffered an occupational injury in the metal stamping industry, and 38.9 workers out of those 48.8 workers endured an occupational hearing loss injury. The incidence rate trend line for hearing loss injuries should be decreasing instead of increasing. It could be plausible that the increase in the hearing loss incidence rate is due to the symptoms of hearing loss being noticed and diagnosed years after the initial and repeated exposure(s), which is often the case with most hearing loss injuries. Or, a significant problem has been revealed, and employers are not protecting their workers like they should be in the metal stamping industry.

3. Tumbling Machines

Tumbling machines vibrate for long periods of time so products and media inside the machine tumble against one another to deburr and provide the desired finish for the products. Tumbling machines come in many different configurations. Round bowl tumbling machines, of interest in this study, are the most common types of tumbling machine used in the metal stamping industry.

The mechanics of tumbling machine operation work are quite simple. The bowl of the tumbling machine is suspended on a casing, where a collection of compression springs is configured to provide the vibration action with the help of either a vertical drive mechanism or a vibratory motor located along the central axis (Domblesky, Cariapa, & Evans, 2003). Gillespie (2009) further states, "With either method the amount of weight placed on the top and bottom of the eccentric system and the angular displacement between the two weights control the following:

- the finishing action (the amount of media vibration against the workpieces)
- the speed at which the mass rolls over within the bowl
- the speed at which the mass rotates around the bowl."

Figure 5 displays a basic diagram of the round bowl tumbling machine with specific parts and items identified.

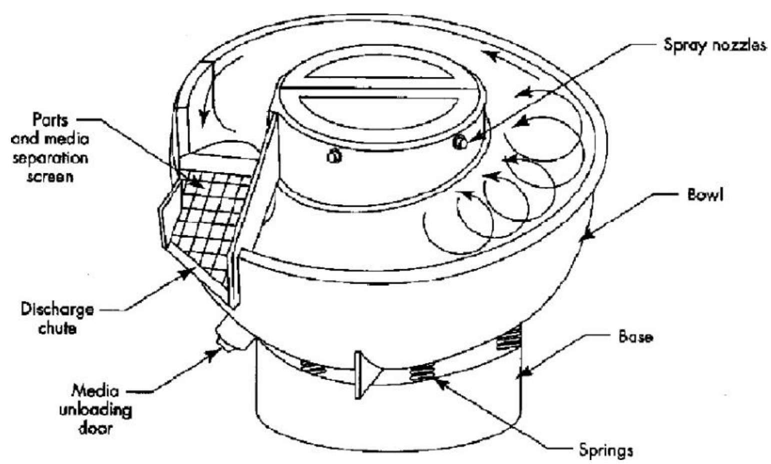

Figure 5 – Basic configuration of a round bowl vibratory finishing machine (tumbling machine). Reprinted from *Mass Finishing Handbook* (p. dd), by L.K. Gillespie, 2007, New York, NY: Industrial Press Inc. Copyright 2007 by Industrial Press Inc.

Figure 6 and Figure 7 show two actual round bowl tumbling machines.

Figure 6 – Round Bowl Vibratory Tumbling Machine. Manufacturer: Vibra Finish, Model: Vibra Hone FCC-300ULE-2 with 10.6 cubic feet capacity.
Kroening, A. (Photograph). (2016)

Figure 7 - Round Bowl Vibratory Tumbling Machine. Manufacturer: Roto-Finish, Model: ER-1516 with 15 cubic feet capacity.
Kroening, A. (Photograph). (2016)

In wet tumbling, the tumbling machine is vibrating and the bowl contains the parts, media, and soap. After processing, the products will migrate to the unloading screen and an unloading lever is lifted so the parts will tumble into the collection tote that collects the finished products. The tumbling machines investigated in this study had broken unloading levers, so tumbling operators had to manually grab and lift the products to the unloading screen, exposing them to more noise.

Some tumbling machines have channels like that pictured in Figure 7, which allows two or three different types of media to be separated in the tumbler. The parts will tumble in each media for a specified amount of time until the tumbling operators move the parts to the next channel containing different media. Parts can obtain multiple finishes in one tumbling machine when the tumbling machine has more than one channel.

4. Tumbling Operators

Tumbling operators must load and unload products into the tumbling machines. The soap is administered automatically through metering pumps. The media within the tumbling machines is changed infrequently. The amount of parts and the desired finish determine how long the parts need to tumble within the tumbling machine. Again, if the tumbling machine has different channels, tumbling operators will have to move the parts manually to the next channel at specified times. If the tumbling duration is long, or the tumbling operator is only operating one tumbling machine, that operator does not have to stay and monitor the tumbling process for the entire shift. The operator can usually do different activities and check on the tumbling operation sporadically until it is complete. However, if the tumbling operator is running products that have a short tumbling time or he/she is running multiple tumbling machines, then it is likely that the operator will be in the tumbling department all day and exposed to the noise.

Products may tumble in the tumbling machine for as little as 15 minutes to as long as 8 hours. The products under study for this paper were tumbling in one machine for a duration of 6-8 hours.

5.Tumbling Operation Noises

Metal stamping companies need to tumble metal products after the metal products are stamped out. The main noise levels produced from the tumbling operation are from the metal products tumbling against one another and tumbling against the media. Aluminum, stainless steel, and steel metal parts are the common types of metal ran in the tumbling machines. When the different types of media that are required are added, then the noise levels increase drastically. The vibratory motor for the tumbling machines generates significant sound levels itself even without anything contained within the bowl.

The unloading activity lasts several minutes but generates significant noise levels. Products travel on the unloading screen and then fall into the collection tote when done tumbling. The unloading screen, unlike the bowl, is not lined with urethane or polyurethane. The unloading screen is constructed of steel, so the metal products tumble and bounce on a steel screen plate, and noise levels generated can be heard by employees working far away.

Noise levels vary depending on the layout of the tumblers and of the material that contain the tumbling machines. The construction materials that make up the walls, floor, and ceilings may help with reducing the sound levels generated from the tumbling process, or the material may reflect, reverberate, or amplify the sounds. Furthermore, how close the tumblers are to walls may also affect the sound levels and how close or far the operators work from the equipment will determine their exposure.

6. Factors Affecting Noise Exposure

The degree of noise exposure is affected by many different factors, some of which can be controlled or considered by the employers, such as:

1. Knowledge of noise induced hearing loss injuries
2. Knowledge of the noise levels generated by the tumbling machines
3. Knowledge of noise exposure data for tumbling operators
4. Configuration of the tumbling machines
5. Engineering controls
6. Hearing Protection

Noise exposures symptoms may not manifest themselves into noticeable symptoms for years, depending on the severity of the exposure. Unlike traumatic injuries like contusions, broken bones, or cuts that elicit immediate and noticeable outcomes; occupational illnesses, like respiratory illnesses and hearing losses, are not taken as seriously, and the risk is perceived as low to employees because the disease develops later and over time. The consequences of noise exposures may not reveal themselves to workers until 5-20 years later when it is often too late to do anything. It is important for the employers and employees understand how noise induced hearing losses occur, the severity, consequences of noise exposures, and the importance of always wearing hearing protection and trying their best to install effective engineering controls. They should know the sound levels generated by the tumbling machines to protect the operators appropriately and chose the best controls. People may hear sound levels differently; especially those who have reduced hearing already. One manager may state that the sound level produced by the tumbling machine(s) is not problematic due to the manager already having reduced hearing. Another manager may state that the tumbling machine(s) are too loud. It is never good to leave safety and health topics, such as, noise levels up to opinion or individual perception. In order to accurately assess the sound levels that a piece of equipment is generating, the proper instrumentation is required, and the equipment should be used by trained professionals like industrial hygienists. When in doubt, even the most basic types of instrumentation, such as, sound level meters that can be installed and used on cells phones, can be used; however, they should only be used to take preliminary measurements of the sound levels released from the tumbling machines. Type II or Type I sound level meters are required and should be properly calibrated and used by trained professionals in order to make accurate noise measurements. The results will determine whether or not the sound levels are problematic, or not, and determine whether controls are required.

Measuring the sound levels generated by the tumblers will determine whether or not employees will be negatively impacted and controls need to be implemented for the machine. Is it also critical that noise monitoring for employees occur, and that the employees are presented the results. Employees may work near the tumbling machines for hours, or for only minutes. The only way that employers can assess whether the controls are protecting the tumbling operators is to perform noise monitoring. Industrial Hygienists or other health and safety professionals can perform noise monitoring for employees to determine whether the noise exposures are above or below OSHA's permissible exposure limits or ACGIH's threshold limit values for an 8-hour Time-Weighted Average (TWA). If an employee's noise monitoring results exceed the OSHA PEL, then the employer must reduce the noise exposure by installing controls, whether engineering, administrative, PPE, or other. Furthermore, the noise monitoring data may state that an employee is below the OSHA PEL or ACGIH TLV and no further action may be required for the employer, except annual noise monitoring.

III. Tumbling Machine Noise Controls

The configuration of the tumbling machines can be a variable for control of noise exposures. The configuration of the department and the floor space can determine how the sound levels impact the tumbling operators. Most manufacturing buildings were originally built for other purposes, and over time altered for most efficient use of floor space, without considering how it will affect noise exposures. The cost to re-locate large and heavy equipment is usually too high to justify for employers. Enclosure of the tumbling machines in a separate room with noise absorbing material installed throughout would help reduce the noise exposure for the tumbling operators. Changing the proximity of the tumbling machines to one another could also aid in reducing the sound levels generated as well. Most tumbling machines are placed right next to a wall, usually concrete. Tumbling machines that are situated right next to one another could also affect sound fields.

Controls for tumbling machines are available. Most brand new tumbling machines have noise covers attached to the machine or available for an additional cost. CLM Vibe Tech (Kalamazoo, MI) manufactures and sells a variety of round bowl tumbling machines that can be manufactured with sound covers or sound hoods. Figure 8 displays a round bowl tumbling machine manufactured by CLM Vibe Tech that has a rigid sound hood attached as a separate component to the tumbling machine. This “[R]igid sound hood is made out of aluminum sheet stock and sound abatement foam. The sound hood is then mounted off of a heavy-duty steel base frame” (“Sound Protection,” 2016).

Figure 8 – Sound Hood installed on CLM Vibe Tech Vibratory Finishing Machine.
(CLM Vibe Tech, 2016)

Sound hoods and noise covers can also be custom built for tumbling machines. Custom-made sound hoods (Figure 9) have a hefty price tag; therefore, companies tend to buy custom made noise covers instead.

Figure 9 – Custom Built Sound Hood.
(CLM Vibe Tech, 2016)

Figure 10 depicts a sound cover manufactured by CLM Vibe Tech that is "made out of heavy-duty vinyl with 1-inch sound abatement foam." This sound cover is the most economical for employers compared to the rigid sound hood while still reducing the sound levels (CLM Vibe Tech, 2016).

Figure 10 – Custom Built Sound Cover
(CLM Vibe Tech, 2016)

The sound hood was not purchased to evaluate the efficiency of this product for this study. A noise cover was purchased to evaluate the efficiency of the product for reducing sound levels and noise exposures. One sound cover was purchased for the Vibra Finish® Vibra Hone tumbling machine (Figure 6). The sound cover was custom built by Highland Products (Union, KY) who partnered with CLM Vibe Tech to create a custom CLM Vibe Tech sound cover. The custom-built sound cover had flaps installed where operators could lift the flap to load parts into the tumbling machine and to move parts to the unloading level. Furthermore, the custom sound cover had an opening for parts to unload off of the tumbling machine into a collection tote. The custom built sound cover is shown in Figure 11. The sound cover can be suspended above the tumbling machine while not in use by using proper rigging techniques; however, while the tumbling machines are operating, the sound cover must lie on the machine to reduce the noise levels the best.

Figure 11 – Sound Cover custom built for study by Highland Products/CLM Vibe Tech.
Kroening, A. (Photograph). (2016)

Operators will adapt to using the sound covers on the tumbling machines over time. They will understand the importance of safety equipment when they are aware of the consequences of not using the equipment. Use of the sound covers will become a habit with continued use.

This study tested the efficiency of reducing the sound levels and noise exposures with the use of the sound cover. The sound cover is designed with heavy-duty vinyl inside and outside stitched together with flexible sound abatement foam. Installation of the sound cover should reduce the noise exposure of the tumbling operators.

IV. Hearing Protection

It is vital that hearing protection devices (HPD's) with the appropriate noise reduction rating (NRR) be worn when the noise exposures are above the OSHA-PEL or the ACGIH-TLV, and if engineering/administrative controls are not feasible or practical. Personal protective equipment is the last option to reduce the noise levels for the tumbling operators. Ear plugs or ear muffs are hearing protection devices that can be worn to protect workers from loud noise exposures. The NRR of a hearing protection device is pre-calculated by the manufacturer. The NRR is used to estimate the decrease in wearer noise exposures by subtracting it from the A-weighted sound levels. An additional safety factor of 7 dB must be included as shown in Equation 2;

$$\text{Estimated exposure (dBA)} = \text{workplace noise level (dBA)} - (\text{NRR} - 7\text{ dB}) \qquad (2)$$

A margin of safety for the NRRs is recommended for evaluating the efficacy of HPDs and engineering noise controls. OSHA recommends reducing published NRRs by 50%. Therefore, the equation for estimating exposures with a margin of safety included in the NRR would be calculated as shown below.

$$\text{Estimated exposure (dBA)} = \text{workplace noise level (dBA)} - \frac{(NRR - 7\ dB)}{2} \qquad (3)$$

Employers can use equation 3 to determine whether related HPD will reduce the noise exposure to acceptable levels with a 50% margin of safety, assuming the HPD is worn correctly. The effectiveness of hearing protection devices is determined by the proper use of the device. Employees need to be trained on how to fit a HPD, its use, and care. Not wearing the HPD correctly will greatly reduce the effectiveness of the HPD, regardless of the NRR.

V. Research Design and Methods

A. Experiment Setup

In order to assess the efficacy of the sound cover for reducing the sound levels generated by the tumbling machine and reducing the noise exposures levels for tumbling operator, noise levels were measured without the sound cover installed over tumbler 2, which is the Vibra

Finish® Vibra Hone tumbling machine, and again with the sound cover installed over the tumbling machine. The tumbling department consists of six tumbling machines. Five of the tumbling machines are round bowl finishing machines, and one tumbling machine is a rotary tumbling machine. Noise levels were measured when operations were considered “normal,” with tumblers 1, 2, and 7 operating.

Sound level readings were taken in designated distances away from tumbling machine #2 without the sound cover on and again with the sound cover on to measure differences in sound pressure levels. The tumbling operators wore noise dosimeters for varying sampling times before the noise cover was installed and after the noise cover is installed to determine if the tumbling operator’s noise exposures decreased.

B. Previous Noise Studies

Noise monitoring for a tumbling operator occurred in May of 2010 at the request of the company, Qualtek Manufacturing, Inc. The company, Qualtek, wanted to see if engineering controls, noise absorbing baffles hung from the ceiling, had been effective at reducing the noise exposure levels for their operators after initial noise monitoring performed in early March 2010 indicated that the noise exposure limits exceeded the OSHA PEL of 90 dBA TWA. The follow-up noise monitoring indicated that after the sound absorbing baffles were hung from the ceiling, the noise levels dropped from 93 dBA to 89 dBA for the tumbling operator. The 89 dBA noise level was still fairly close to the OSHA PEL and the sampling was only performed for 245 minutes; therefore, it was recommended that follow-up sampling for the entire shift be performed and that further controls try to be installed. The tumbling operators were still required to wear hearing protective devices .

C. Sound Level Measurements

The sound levels generated by the tumbling machine(s) were collected using a sound level meter (SLM). Sound level meters sense acoustic pressure and indicate the sound level. The sound level meter consists of a microphone, preamplifier, amplifier, frequency weighting filters, and a digital readouts. Most sound level meters will provide either a liner sound pressure level (dB) or a weighted sound pressure level (dBA, dBC, etc.) depending on the meter. Sound level meters work by having the acoustic pressure sensed by the microphone which then sends an electrical signal input to a preamplifier. The conditioned signal is then processed through weighting filters set by the user. After the filtering, the signal is changed by the squaring operation which is necessary since sound pressure level (SPL) is a function of pressure squared. Finally, a moving average of the sound pressure level is generated and presented digitally by an exponential averaging filter which may be FAST or SLOW depending on whether the meter's response is set to FAST or SLOW. OSHA; however, will not accept a FAST response when measuring sound levels for compliance measuring. SLOW responses have a time constraint of measuring every 1 second.

There are four types of sound level meters. Type 0 SLM's are intended to be used in laboratory environments where they will be used as a reference standard and are not used in the field. Type 1 SLM's can be used in the laboratory or the field and will have errors that do not exceed 1 dB. Type 2 SLM's are intended for general use in the field and have errors of ±2 dB. Finally, Type S SLM's are intended for special purposes.

1.Equipment Used

Sound level measurements for this study were collected using the 3M® SoundPro Type I Sound Level Meter with integrated 1/1 or 1/3 octave band filters. The sound level meter was calibrated with the AC 300 Calibrator. Calibration of the sound level meter occurred on-site in a quiet office immediately before and after noise monitoring. The wind screen was utilized on the microphone.

2.Locations Sampled

Sound level readings using the Sound Pro SLM were collected in varying distances away from tumbling machine #2 since that was the tumbling machine that had the custom-built sound cover made and installed. Sound measurements were collected right over the tumbling machine and then collected every foot behind, in-front, right, and left of the tumbler until measurements of 10 feet in each direction were collected.

One 3M Edge eg5 dosimeter was used as an area noise monitoring device for 8 hours, and that noise dosimeter was placed 1 foot left of tumbler #2 on the control panel. Another 3M Edge eg5 dosimeter was placed between tumbler #2 and tumbler #1 as another area noise dosimeter for 8 hours to determine the effect tumbler #2 had on the noise levels when both tumblers were operating simultaneously.

3. Sound Level Measurement Procedures

After the Sound Pro sound level meter was calibrated, the sound level meter was set to collect A-weighted sound levels, with a 1/1 octave band filter set, and SLOW response. At tumbler #2, the sound levels for each frequency, starting at 16 Hz and ending at 16 KHz were collected and recorded on the appropriate worksheet. If distances were obstructed with equipment, the sound level for that distance was not recorded.

4. Analysis of the Overall SPL Pre and Post Sound Cover

Measurements were recorded using the frequency filter. The overall SPL for each distance was calculated using equation 3;

$$Lp_f = 10 \log (\sum 10^{Lp/10}) \quad (3)$$

where Lp is the sound pressure level at each frequency, and Lp_f is the overall sound pressure level. The overall sound pressure level calculated for the locations were used to create a noise map to compare pre noise cover and post sound cover. The noise map depicting the differences in sound levels before and after the sound cover are shown in Figure 14 and 15 in the results section.

5. Limitations of the Sound Level Meter Measurements

There are a variety of metal parts that will tumble in the tumbling machines. Sound level measurements were measured for two different types of metal parts tumbling due to production demands. Different sized metal parts will produce different noise results. The sound cover may reduce noise levels for one type of metal part yet may not work effectively for reducing the sound levels for a different sized part that may be bigger or configured differently.

All sound level measurements were recorded when both tumbler #1 and tumbler #2 were running. Due to production demands, sound levels could not be measured when only tumbler #2 was running. This was the tumbler with the custom sound cover installed. The resulting measurements are for the combined sounds of both tumblers, one covered and the other not.

Only one sound cover was custom-built for one of the main tumbling machines, tumbler #2. If each tumbler had a sound cover installed the sound levels would likely decrease. If it was determined that the sound cover is effective at reducing the sound levels and noise exposures for workers, covering more or all tumblers would reduce noise.

D. Noise Exposures

Personal noise exposures for the workers were obtained using noise dosimeters. Noise dosimeters are worn by the employees for a specified duration, usually their entire work shift. Noise dosimeters work very similarly to sound level meters (SLM's). A noise dosimeter is made of a microphone with a preamplifier, a weighted network, FAST or SLOW response times, an internal clock, a calculator, and memory to store logged data. Noise dosimeters work by having the microphone sense a sound pressure and generate an electric signal that will be increased by the preamplifier. The signal is then regulated to an applicable level by the range control (dB range). The signal then goes through a filter weighting (A, C, Z). The response circuit of FAST or SLOW dampens the signal appropriately until the results are displayed on the dosimeter's digital screen. The noise dosimeter has an internal clock that tracks the sampling time. Dosimeters have the ability to record how long sound levels exceed the set upper limits, and the dosimeter's internal calculator will compute the average sound level (L_{avg}), a dose (percent), and the Time-Weighted Average (TWA).

1. Noise Dosimeters Used

Noise exposure samples were collected using 3M® Edge eg5 noise dosimeters that were calibrated immediately before and after sampling using the AC 300 Calibrator. All dosimeters were setup for OSHA PEL compliance measurements with the following settings: 5 dB exchange rate, A-weighting frequency, SLOW response, 90 dBA criterion level, and a threshold of 90 dBA. Employees wore the noise dosimeters in order to measure their daily exposure to noise levels. Two noise dosimeters were also used as area noise monitors to measure the time-weighted average (TWA) for locations designated next to the tumbling machine to simulate a worst-case scenario if a worker were to work right next to the tumbling machine for 10.5 hours. Noise dosimeters were used pre noise cover and post noise cover.

2. Employees Sampled

Three tumbling operators work varying shifts. One tumbling operator works first shift (Mon-Thurs: 6AM – 4:30PM). The second tumbling operator works 2nd shift (Mon-Thurs: 4PM – 2:30AM), and the third operator works 3rd shift (Thurs: 6AM-4:30PM and Fri & Sat: 5AM-5:30PM). Two out of the three tumbling operators wore dosimeters before the installation of the noise cover and again after the installation of the noise cover.

The third shift tumbling operator was sampled pre noise cover for the majority of his work shift, since he would be working in the tumbling department the entire shift, loading, unloading, and inspecting parts. The third shift tumbling operator wore the noise dosimeter for a sampling time of 8 hours, 30 minutes pre noise cover and for 8 hours and 11 minutes post noise cover a few weeks later. Although the sampling duration was over 8 hours, the sampling did not cover his entire work shift of 10.5 hours. The noise dosimeter was not removed for breaks or lunch. Figure 12 displays the third shift tumbling operator's noise exposure profile for both pre and post noise cover noise sampling.

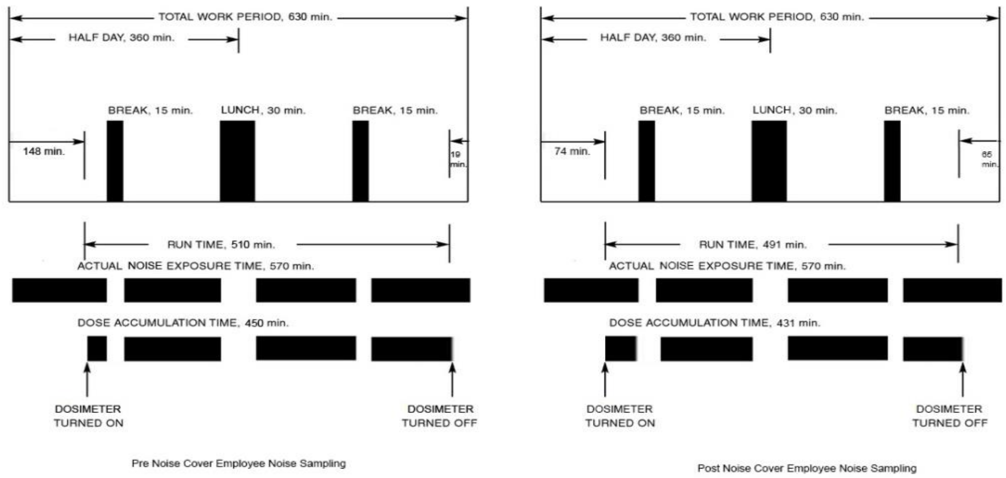

Figure 12: Third shift tumbling operator pre noise cover and post noise cover noise exposure cycle and dosimeter utilization period (10-hour workday).

The first shift tumbling operator was sampled for only two hours pre noise cover out of his work shift since he was would not be working in the tumbling department consistently. The first shift tumbling operator wore the noise dosimeter for a sampling time of 2 hours and 25 minutes before the noise cover was installed. The first shift tumbling operator only had to operate, load, and unload the tumbling machines, which took 2 hours and 25 minutes. The rest of his shift, he would be doing different activities outside of the tumbling department waiting for the tumbling operation to complete until returning again to unload and load parts again. The noise dosimeter was started when the tumbling operator entered the tumbling department to load and unload parts, then the noise dosimeter was stopped when the operator exited the tumbling department to do different activities and started again to unload and load parts and then stopped permanently when exiting the tumbling department for the final time for his shift.

The first shift tumbling operator wore the noise dosimeter after the installation of the noise cover for a sampling time of 7 hours and 42 minutes. Figure 14 displays the first shift tumbling operator's noise exposure profile pre and post noise cover.

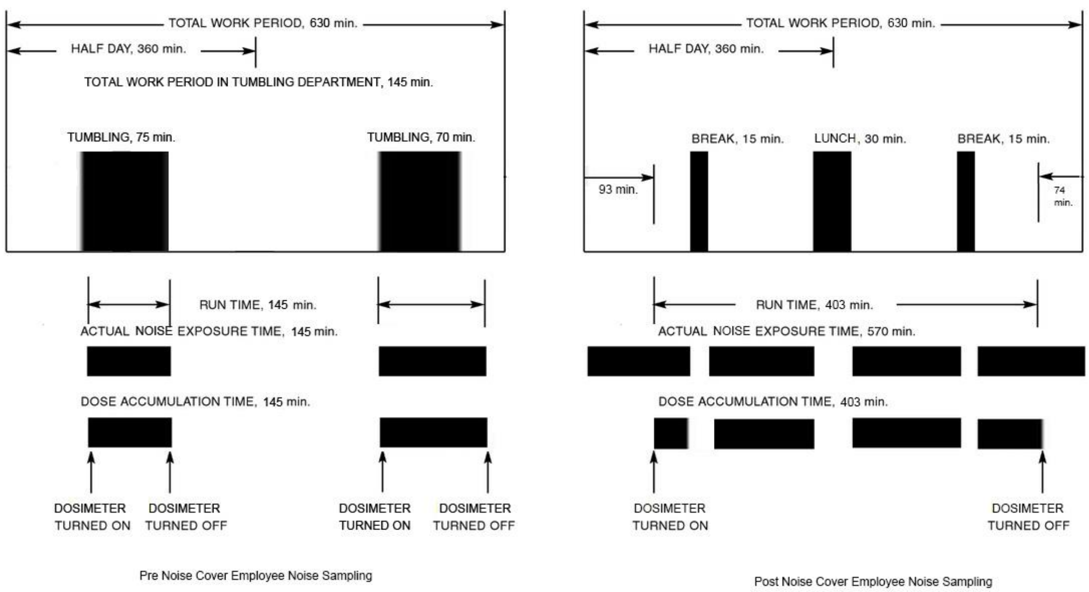

Figure 13 – First shift tumbling operator pre noise cover and post noise cover noise exposure cycle and dosimeter utilization period (10-hour workday).

One 3M Edge eg5 dosimeter was used as an area noise monitoring device for 8 hours, and that noise dosimeter was placed 1 foot left of tumbler #2 on the control panel. Another 3M Edge eg5 dosimeter was placed between tumbler #2 and tumbler #1 as another area noise dosimeter for 8 hours to determine the effect tumbler #2 had on the noise levels when both tumblers were operating simultaneously. The noise dosimeters used to measure the area noise levels for 8 hours occurred in the same location again after the noise cover was installed.

3. Noise Dosimetry Sampling Procedures

The noise dosimeters were placed on the shoulder of the employees for sampling. Noise monitoring and data logging began when the start button was pressed on the dosimeter and stopped when the stop button was pressed.

The two noise dosimeters that would be used as area monitoring were placed in the appropriate designated locations after calibration. These two dosimeters would not only measure the area noise levels for a specified duration of time, but it would capture the absolute worst case noise exposure data if an operated work right next to the tumbling machines for the entire shift.

4. Analysis of the Noise Dosimeters

After sampling, the noise dosimeters were post calibrated immediately. Analysis of the noise dosimeter sampling was performed using 3M's™ Detection Management Software (DMS). The 3M™ Detection Management Software DMS user manual states that "3M™ Detection Management Software DMS is used to record, report, chart and analyze data collected for assessment of select occupational health hazards in the workplace. Designed for dosimetry, sound level measurements, heat stress assessments and environmental monitoring, the software helps safety and occupational professionals:

- Retrieve, download, share and save instrument data
- Generate insightful charts and reports
- Export and share recorded data
- Perform "What if" analysis and recalculate data based on selected time intervals
- Set up instruments and check for firmware updates." (2012, p. 1).

After the data was recorded and retrieved using the 3M™ DMS, tables, charts, and graphs were created in Microsoft Excel in order to correct and assess exposure results that will be discussed in the results section. The null hypothesis stated that there would not be a significant difference ($p \geq 0.05$) in sound pressure levels prior to the installation of the noise cover compared with the sound pressure levels after the installation of the noise cover. A two sided t-test was computed to evaluate the efficacy of the noise cover.

5.Limitations of the Noise Dosimetry Sampling

The limitations stated for the sound level measurements are the same for the noise dosimetry sampling. Only two types of metal parts were tumbling, noise exposure sampling occurred when both tumbler #1 and tumbler #2 were running and not only tumbler #2 was running, and only one sound cover was purchased and installed.

A big limitation occurred for one of the tumbling operators. Due to the work shift, the tumbling operator had to operate the noise dosimeter on their own. The operator pressed the play button when he entered the tumbling department and stopped the dosimeter when he left the department for the shift. Since the tumbling operator was not trained on the proper handling and operation of the noise dosimeter, the operator could have mishandled and introduced other noises during the sampling period which would affect the overall noise exposure results.

VI. Results and Discussion

The results for each sound pressure level sampling period and noise exposure monitoring pre and post noise cover are displayed and discussed in the following sections.

A. Sound Pressure Levels Measurement Results

Table 2 shows the results of the overall sound pressure level results for varying distances measured away from tumbler #2 in every direction without the use of the noise cover and with the noise cover.

Table 2: Overall Sound Pressure Levels (dBA) Without and With Sound Cover

	WITHOUT SOUND COVER		WITH SOUND COVER	
	Overall Sound Pressure Level (dBA)	**Exceed OSHA PEL (90 dBA)**	**Overall Sound Pressure Level (dBA)**	**Exceed OSHA PEL (90 dBa)**
RIGHT ABOVE TUMBLER 2	94.1	Yes	85.5	No
1 FOOT				
1 ft Right	93.8	Yes	87.8	No
1 ft Left	92.8	Yes	82.1	No
1 ft Infront	95.1	Yes	86.9	No
1 ft Behind	92.6	Yes	83.9	No
2 FEET				
2 ft Right	94.7	Yes	88.1	No
2 ft Left	90.3	Yes	83.8	No
2 ft Infront	92.5	Yes	85.6	No
2 ft Behind	91.6	Yes	86.2	No
3 FEET				
3 ft Right	96.1	Yes	90.7	No
3 ft Left	89.6	No	83.3	No
3 ft Infront	89.1	No	84.9	No
4 FEET				
4 ft Right	96.8	Yes	84.7	No
4 ft Left	88.6	No	83.1	No
4 ft Infront	89.1	No	83.5	No
6 FEET				
6 ft Left	88.2	No	82.5	No
6 ft Infront	91.1	Yes	83.5	No
9 FEET				
9 ft Right	99.9	Yes	86.0	No
10 FEET				
10 ft Right	93.6	Yes	85.7	No
10 ft Left	86.9	No	81.3	No
10 ft Infront	87.1	No	80.6	No
Mean	**92.1**		**84.7**	
Standard Deviation	**3.41**		**2.42**	

Table 2 display the difference in the sound levels without the noise cover and with the noise cover installed. It is evident that there was a reduction in the sound pressure levels when the noise cover was installed. Some distances away from Tumbler #2, such as, 1 foot left of tumbler #2 show significant changes in the sound pressure levels after the installation of the noise cover. The average change in the sound pressure level after the installation of the noise cover was 7.26 dBA. A 7.26 dBA change in sound pressure level is quite large. It was hypothesized that the noise cover would reduce the sound pressure level, but it was not expected to have such a drastic change. The 1/1 octave band analysis sound level measurements table that displays the sound level measurement for each frequency in each location pre and post noise cover, which was then used to calculate the overall sound pressure level for each location is attached in Appendix A.

B. Noise Mapping

The author recorded sound levels measurements at varying distances away from Tumbler #2. The measurements were recorded on a portion of the floorplan of the tumbling department. Figure 14 displays a colored noise map that displays the sound level ranges that cover an area of 432 feet before the installation of the sound cover.

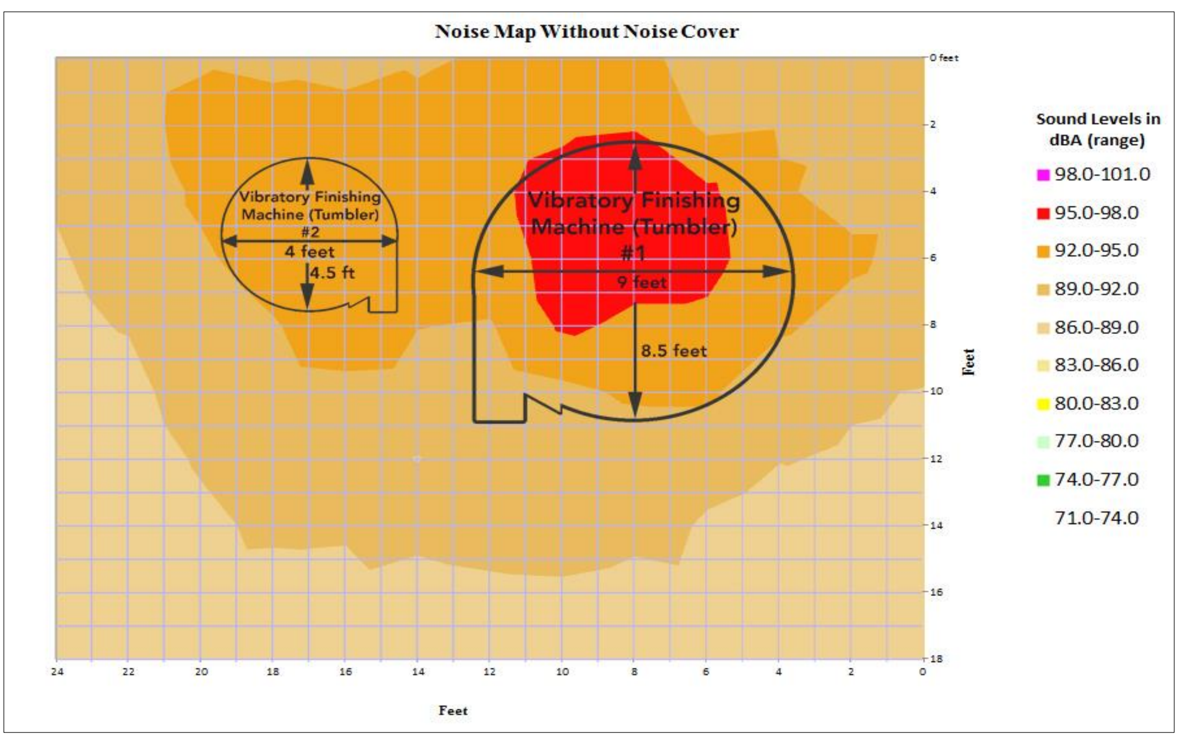

Figure 14 – Noise map without noise cover

Figure 15 shows the changes of the noise map of the same 432 feet after the installation of the noise cover on Tumbler #2.

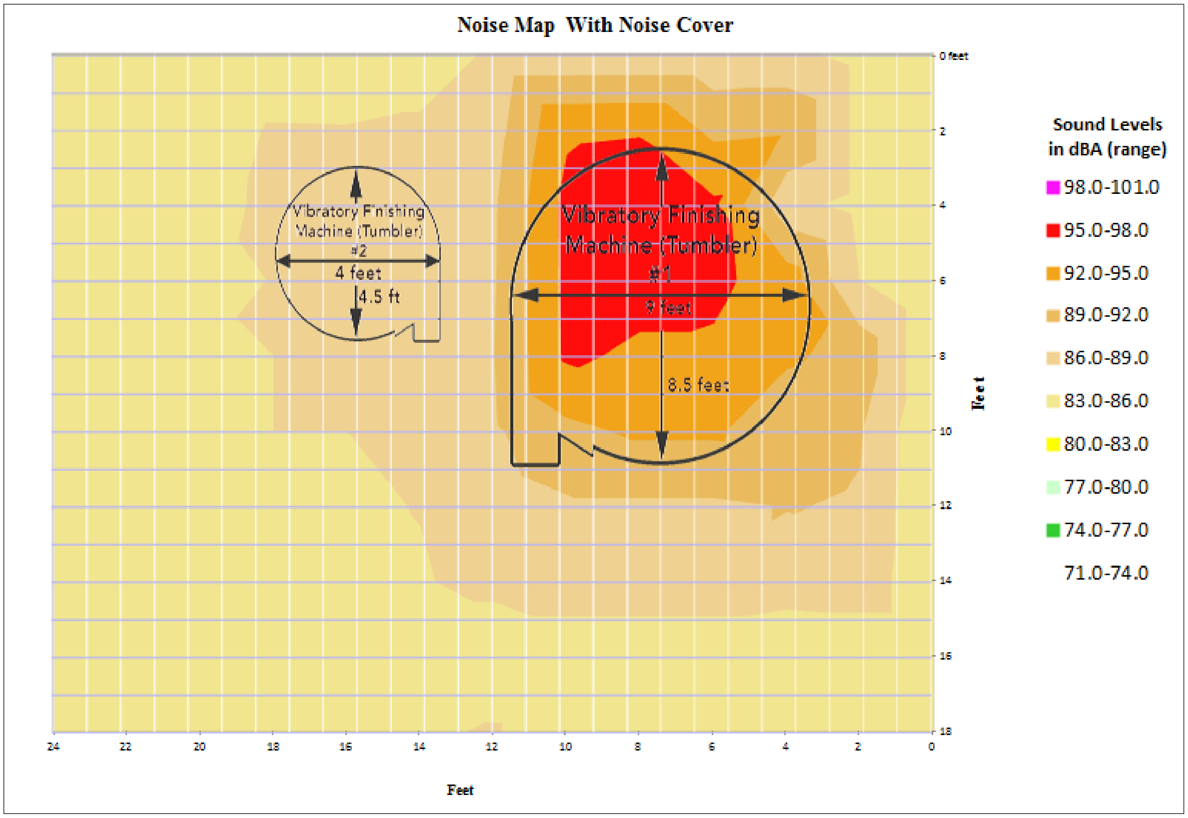

Figure 15 – Noise map with noise cover

The changes in sound pressure levels in the area close to tumbler #2 after the installation of the noise cover are obvious. Before the noise cover, the area surrounding tumbler #2 had sound pressure levels measured and recorded in the 92.0 dBA to 95.0 dBA range. After the installation of the noise cover, the same area around tumbler #2 had sound pressure levels measured and recorded in the 89.0 dBA to 92.0 dBA and 86.0 dBA to 89.0 dBA range. The two noise maps show a difference in the noise levels recorded in the area around tumbler #2 with and without the noise cover installed.

C. Employee Sampling Results

Two tumbling operators wore the noise dosimeters for different sampling times. Table 3 displays the tumbler's operators noise exposure results without the noise cover installed and Table 4 displays the tumble operator's noise exposures with the noise cover installed.

Table 3: Noise Exposure Results without Noise Cover

Position	**Sampling Time (Minutes)**	**Typical Shift Time (Minutes)**	**Measured Dose (%)**	**Projected Dose (%) (10.5 hrs or 630 mins)**	**Calculated 8-hr TWA (dBA)**	**Meets or Exceeds OSHA Action Level (85 dBA)**	**Meets or Exceeds OSHA PEL (90dBA)**
First Shift Tumbling Operator	147	630	69	295	97.8	Yes	Yes
Third Shift Tumbling Operator	510	630	151.4	187	94.5	Yes	Yes

Table 4: Noise exposure data with Noise Cover

Position	**Sampling Time (Minutes)**	**Typical Shift Time (Minutes)**	**Measured Dose (%)**	**Projected Dose (%) (10.5 hrs or 630 mins)**	**Calculated 8-hr TWA (dBA)**	**Meets or Exceeds OSHA Action Level (85 dBA)**	**Meets or Exceeds OSHA PEL (90dBA)**
First Shift Tumbling Operator	462	630	94.1	128.3	91.8	Yes	Yes
Third Shift Tumbling Operator	491	630	94.4	121.1	91.4	Yes	Yes

The first shift operator only worked 2.4 hours pre noise cover and then 7.7 hours post noise cover in the tumbling department, but the normal work shift in the tumbling department is 10.5 hours or 630 minutes. However, we want to compare the exposure to an 8-hr TWA for

OSHA compliance; therefore, the measured dose will be converted to the projected dose using equation 4;

$$D(H)^* = D(\text{measured}) \times H^* / T^*, \text{ percent} \quad (4)$$

where T* is the actual period sampled, and H* is the whole shift duration. Once the corrected dose is obtained, the equivalent 8-hour TWA can be calculated using equation 5;

$$TWA = 16.61 \, \text{Log}_{10} (D/100) + 90 \text{ dBA} \quad (5)$$

where D is the percent (%) dose for the whole shift. Both tables state whether or not the exposure results exceed the OSHA Action level of 85 dBA and the OSHA PEL of 90 dba for an 8 hour Time-Weighted Average (TWA). The same calculations occurred for the third shift tumbling operator noise exposure data to compare his exposure to an 8-hr TWA for OSHA compliance.

The two tumbling operators were exposed to a calculated 8-hour TWA that exceeded the OSHA PEL and the OSHA Action level before and after the installation of the noise cover; however, the noise exposure values decreased for each operator after the noise cover was installed. The first shift tumbling operator experienced a reduction of 6 dBA after the installation of the noise cover. The third shift tumbling experienced a reduction of 3.1 dBA after the installation of the noise cover. Although the reduction in noise exposure for the operators was not as drastic as the reduction seen in the area sound level measurements after the installation of the noise cover, the reduction in noise does indicate that the noise cover is a viable noise control. Again, there were some limitations to this study that could have influenced the sampling and results. To fully evaluate the effectiveness of the noise cover, sampling with just tumbler #2 operating before and after the noise cover should have occurred. Although the personal noise sampling results are important and help support the hypothesis that a reduction in sound pressure levels would occur after the installation of the noise cover, the operators could not realistically work just on tumbler # 2 and operate only tumbler #2. Therefore, the personal noise sampling results are not the best to compare the effectiveness of an engineering control such as the noise cover.

D. Area Noise Sampling Results

Two 3M Edge eg5 noise dosimeters were used to obtain area noise exposures to simulate worst case worker's personal noise exposures if the workers worked the entire shift (10.5 hours) in the tumbling department right next to Tumbler #2. Furthermore, the area noise sampling is better to evaluate the effectiveness of an engineering control since there are not as many variables. An area noise exposure was obtained before the noise cover and again after the noise cover was installed. Table 5 displays area noise exposure results without the noise cover installed and Table 6 displays the area's noise exposures with the noise cover installed.

Table 5: Area Noise Sampling Results without Noise Cover

Area	Sampling Time (Minutes)	Typical Shift Time (Minutes)	Measured Dose (%)	Projected Dose (%) (10.5 hrs or 630 mins)	Calculated 8-hr TWA (dBA)	Meets or Exceeds OSHA Action Level (85 dBA)	Meets or Exceeds OSHA PEL (90dBA)
1 Foot Left of Tumbler #2 (on controller)	481	630	201.7	264	97.0	Yes	Yes
1 Foot Right of Tumbler #2	481	630	141.1	184.8	94.4	Yes	Yes

Table 6: Area Noise Sampling Results with Noise Cover

Area	Sampling Time (Minutes)	Typical Shift Time (Minutes)	Measured Dose (%)	Projected Dose (%) (10.5 hrs or 630 mins)	Calculated 8-hr TWA (dBA)	Meets or Exceeds OSHA Action Level (85 dBA)	Meets or Exceeds OSHA PEL (90dBA)
1 Foot Left of Tumbler #2 (on controller)	464	630	94.1	127.8	91.8	Yes	Yes
1 Foot Right of Tumbler #2	491	630	81.3	104.3	90.3	Yes	Yes

The area noise sampling occurred for 8 hours, but in order to simulate an entire 10.5 shift that the operators work every day, the measured dose was converted to the projected dose using equation 4. The equivalent 8-hour TWA was then calculated using equation 5. The two area noise sampling results that simulate worst case personal noise exposures indicate that if worker's were to work next to Tumbler #2 for their entire shift, then they would be exposed to a calculated 8-hour TWA that exceeded the OSHA PEL and the OSHA Action level.

There was a reduction of 5.2 dBA for area noise sampling location 1 (1 foot left of tumbler #2) after the installation of the noise cover. A reduction of 4.1 dBA for the area sampling #2 situated 1 foot right of tumbler #2.

E. Discussion

The objective of this study was to assess whether or not noise covers are effective in reduction the noise exposure levels for tumbling operators. The noise sampling data suggests that the noise exposures without the noise cover installed was above OSHA noise limits and ACGIH noise limits; thus, a hearing conservation program and hearing protection devices are required for the tumbling department. The sound baffles that were installed previously and studied separately are not working efficiently to reduce the noise levels below the OSHA-PEL and OSHA Action Level.

With the noise cover installed, the data indicates that the noise exposure levels are still above the OSHA-PEL and OSHA Action level and ACHIG limits. However, the noise cover did decrease the noise levels by an average of 4.6 dBA compared to the noise exposure levels without the noise cover installed. Further noise sampling needs to be completed to fully evaluate the effectiveness of the noise cover. Sampling with only one tumbling machine running without the noise cover and later with the noise cover is required. A 4.6 dBA reduction in the sound levels is significant with regard to noise exposure. It may be a factor in lowering sound levels below OSHA's permissible exposure limits and it may prevent occupational hearing loss.

F. Controls

Noise covers for the tumbling machines appear to be a solution for reducing the sound levels and noise exposures for the tumbling operators. Furthermore, installing noise absorbing material throughout the department may also help with reducing the overall noise levels. The cost for the installing the material may be problematic, especially if the material will only reduce the sound levels a small amount.

G. Hypothesis Testing

Null Hypothesis (H_0):There will not be a significant difference ($p \geq 0.05$) in sound pressure levels prior to the installation of the noise cover compared with the sound pressure levels measured after the installation of the noise cover

Alternative Hypothesis (H_1): There will be a significant difference ($p < 0.05$) in sound pressure levels prior to the installation of the noise cover compared with the sound pressure levels measured after the installation of the noise cover

A two sample *t* test was performed in order to compare the means of the noise exposure results for the group before the installation of the noise cover and for the group after the installation of the noise cover.. The t-value calculated resulted in a value of $t = 4.91$, and the probability of this result, assuming the null hypothesis was $p \approx 0.0027$. There is a 0.27% chance this could have happened by coincidence. Similar results would occur 99.3 times if 100 tests were run. Since the p-value is less than 0.05, the null hypothesis is rejected.

The results show the noise cover is effective in decreasing the noise exposures for the tumbling operators.

H. Conclusion

Occupational noise induced hearing losses are serious injuries that leave the employee and their family and friends with a diminished quality of life. Employers are typically concerned with getting the job done, instead of worrying about their worker's health and safety. It is a challenge to convince employees to protect their hearing when the consequences of occupational noises are not immediate, and they typically manifest themselves 5-20 years later.

Injury reports indicate that the occupational noise induced hearing losses are slightly rising when they should be decreasing. Either the employers are not fully protecting their workers to the best of their ability, or workers are reporting more and more hearing losses that are now starting to get noticed and diagnosed years after the initial exposures. Employers are liable for the noise induced hearing loss claims even though the workers were trained and given the controls to decrease their exposures. Employers that truly care about their worker's health will continually strive to completely eliminate or reduce the noise levels through the use of engineering controls and leave the use of personal protective equipment as the absolute last resort.

Cost effective engineering controls are needed to reduce the noise exposures for tumbling operators. Noise covers can be custom made for a relatively inexpensive price and they can be made for many different sized round bowl tumblers. The noise covers lay right on-top of the tumbling machines, reducing the sound levels right at the source.

I. Recommendations

To support the claim that the noise covers have effectively reduced the noise levels below OSHA's PEL, additional noise monitoring using a bigger sample size that covers the employee's entire shift is required in the future. Furthermore, noise monitoring needs to occur when different sized metal parts are ran and when all tumbling machines are operating and only one tumbling machine is operating with the sound cover on.

The ultimate model set up for the tumbling machines would consist of locating all the tumbling machines in an enclosed room that has noise absorbing material installed throughout. Furthermore, noise covers would be installed for each tumbling machine. It is not cost effective, nor practical, for employers to setup the tumbling machines as described above. If employers can purchase noise covers for the tumbling machines one at a time, then they will be protecting their workers in a cost-effective manner.

VII. References

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Appendix A: Raw Data

Pre Noise Cover Sound Level Measurements												
LOCATION	16 Hz	31.5 Hz	63 Hz	125 KHz	250 KHz	500 KHz	1 KHz	2 KHz	4 KHz	8 KHz	16 KHz	Overall Sound Pressure Level (dBA)
Location 1												
Right over Tumbler 2	48.9	49.4	62.2	70.5	73.5	78.9	83.2	85.5	90.5	88.6	77.9	94.1
1 FOOT												
1 ft Right	42.9	47.5	60.6	71.5	70.7	78.1	83.7	86.0	89.8	88.3	77.8	93.8
1 ft Left	52.8	56.6	59.6	68.9	71.6	77.6	82.0	84.4	88.6	87.9	77.8	92.8
1 ft Infront	86.7	54.6	64.0	71.2	71.5	79.0	82.9	86.1	90.4	89.3	79.1	95.1
1 ft Behind	50.5	62.2	61.2	69.3	71.7	78.4	82.3	84.0	88.9	86.8	76.8	92.6
2 FEET												
2 ft Right	47.0	49.1	59.2	72.6	71.8	79.0	84.0	87.3	90.7	88.9	79.1	94.7
2 ft Left	53.8	55.6	58.4	67.9	71.0	76.8	80.1	82.3	86.1	84.5	75.2	90.3
2 ft Infront	45.6	54.2	61.0	70.5	71.0	77.7	81.8	84.4	88.2	87.6	76.0	92.5
2 ft Behind	50.7	62.3	60.3	70.6	69.2	78.8	81.2	83.2	87.4	86.2	75.9	91.6
3 FEET												
3 ft Right	50.6	50.4	63.8	73.1	71.8	79.3	84.0	88.0	92.3	90.9	80.9	96.1
3 ft Left	53.8	56.1	58.4	67.1	69.3	76.1	79.8	81.7	85.5	83.7	74.2	89.6
3 ft Infront	46.1	55.1	59.9	68.6	76.0	79.8	81.9	84.7	82.6	72.0	73.4	89.1
4 FEET												
4 ft Right	48.3	49.3	64.4	73.8	72.2	79.7	85.0	89.0	93.2	91.2	80.1	96.8
4 ft Left	54.5	55.8	57.0	66.5	68.8	74.9	79.1	80.8	84.4	82.5	73.5	88.6
4 ft Infront	46.1	55.1	59.9	68.6	76.0	79.8	81.9	84.7	82.6	72.0	73.4	89.1
6 FEET												
6 ft Left	54.6	54.1	57.7	66.9	68.3	75.5	79.6	80.4	83.7	81.9	72.3	88.2
6 ft Infront	44.4	55.4	58.5	67.6	69.9	76.8	79.7	81.1	83.1	81.2	88.2	91.1
9 FEET												
9 ft Right	55.7	56.7	66.3	75.6	72.0	80.7	88.2	91.1	95.7	94.6	84.8	99.6
10 FEET												
10 ft Right	55.1	56.6	64.6	75.1	72.2	78.3	84.0	87.0	81.0	90.7	81.2	93.6
10 ft Left	54.9	54.1	59.1	67.7	68.0	74.3	77.9	79.4	82.5	80.6	71.0	86.9
10 ft Infront	69.4	55.7	60.6	67.2	68.2	75.7	78.5	79.8	82.4	80.0	69.7	87.1

Post Noise Cover Sound Level Measurements												
LOCATION	**16 Hz**	**31.5 Hz**	**63 Hz**	**125 KHz**	**250 KHz**	**500 KHz**	**1 KHz**	**2 KHz**	**4 KHz**	**8 KHz**	**16 KHz**	**Overall Sound Pressure Level (dBA)**
Location 1												
Right over Tumbler 2	48.9	49.4	62.2	70.5	73.5	78.9	83.2	85.5	90.5	88.6	77.9	94.1
1 FOOT												
1 ft Right	39.3	50.5	52.2	67.0	69.5	73.9	78.5	81.6	83.2	81.1	69.6	87.8
1 ft Left	31.0	52.5	51.1	65.0	67.5	72.2	74.5	76.6	76.3	72.5	59.2	82.1
1 ft Infront	37.3	49.5	50.3	63.8	66.3	68.5	79.1	77.1	83.8	80.2	66.3	86.9
1 ft Behind	30.8	53.5	51.2	65.5	68.1	73.3	75.8	78.3	78.7	75.1	62.7	83.9
2 FEET												
2 ft Right	40.5	45.8	52.3	67.2	69.4	73.7	78.2	81.5	83.7	81.8	70.4	88.1
2 ft Left	32.2	50.0	53.3	66.6	67.6	72.8	76.6	78.3	78.2	74.9	62.5	83.8
2 ft Infront	37.0	54.1	56.2	69.0	69.4	74.0	77.5	79.3	80.3	78.0	67.4	85.6
2 ft Behind	33.8	55.0	82.4	64.8	68.1	72.1	75.7	77.9	78.8	75.7	62.5	86.2
3 FEET												
3 ft Right	46.0	47.7	56.6	69.2	71.3	75.6	80.6	83.5	86.1	85.2	74.3	90.7
3 ft Left	34.8	48.2	53.4	65.0	69.2	72.5	75.5	77.6	78.0	74.0	60.8	83.3
3 ft Infront	35.1	54.2	56.3	67.5	70.0	74.1	76.4	78.9	79.6	77.0	66.4	84.9
4 FEET												
4 ft Right	34.6	46.5	53.4	66.5	69.5	72.4	76.6	78.4	79.5	77.2	66.4	84.7
4 ft Left	31.3	46.4	53.8	64.0	68.1	73.1	75.7	77.8	77.4	73.2	60.7	83.1
4 ft Infront	32.9	53.9	57.6	66.4	68.0	72.1	75.4	77.6	78.4	75.4	63.5	83.5
6 FEET												
6 ft Left	37.0	44.9	54.1	64.2	69.1	72.1	74.9	76.7	77.0	73.4	60.6	82.5
6 ft Infront	32.9	53.9	57.6	66.4	68.0	72.1	75.4	77.6	78.4	75.4	63.5	83.5
9 FEET												
9 ft Right	49.2	51.7	56.5	68.3	70.0	74.7	77.2	79.0	81.2	78.9	67.7	86.0
10 FEET												
10 ft Right	50.2	52.7	54.5	66.1	70.1	74.5	77.1	78.8	80.8	78.6	67.5	85.7
10 ft Left	31.7	44.2	54.2	64.5	67.3	70.7	73.7	75.7	75.8	72.1	59.2	81.3
10 ft Infront	35.7	54.5	50.3	62.4	68.7	71.7	73.9	75.2	72.9	71.1	57.5	80.6

Summary Data Panel (Pre Noise Cover)			
Run Time: 8:30:45	Serial: ESP050010	Model: Edge eg-5	Employee: 3rd shift tumbler
Criterion Level: 90 dB	Exchange Rate: 5 dB	Threshold: 90 dB	Weighting: A-weighting
Description	**Meter/Sensor**	**Value**	**Compliance**
Start Date	2	2/4/2016	OSHA PEL
Start Time	2	7:48:37 AM	
Dose	2	151.4 %	
Lavg	2	92.5 dB	
LasMax	2	116.3 dB	
Lcpk	2	--	
Pdose (8:00)	2	142.3 %	
PKtime	2	2/4/2016 3:03:05 AM	
TWA	2	92.9 dB	
ProjectedTWA (8:00)	2	92.5 dB	
Criterion Level	2	90 dB	
Weighting	2	A	
Exchange Rate	2	5 dB	
Projection Time	2	480 mins.	
Peak Weighting	2	Z	
Int Threshold Enable	2	True	
Integrating Threshold	2	90 dB	
Run Time (RT)	2	08:30:45	
UL (115)	2	00:00:09	
End Date	2	2/4/2016	
End Time	2	4:19:22 PM	

Summary Data Panel (Post Noise Cover)			
Run Time: 7:42:46	Serial: ESL010390	Model: Edge eg-5	Employee: 3rd shift tumbler
Criterion Level: 90 dB	Exchange Rate: 5 dB	Threshold: 90 dB	Weighting: A-weighting
Description	**Meter/Sensor**	**Value**	**Compliance**
Start Date	2	2/28/2016	OSHA PEL
Start Time	2	7:33:24 AM	
Dose	2	94.1%	
Lavg	2	89.8 dB	
LasMax	2	117.3 dB	
Lcpk	2	--	
Pdose (8:00)	2	97.6 %	
PKtime	2	2/28/2016 8:18:55 AM	
TWA	2	89.5 dB	
ProjectedTWA (8:00)	2	89.8 dB	
Criterion Level	2	90 dB	
Weighting	2	A	
Exchange Rate	2	5 dB	
Projection Time	2	480 mins.	
Peak Weighting	2	Z	
Int Threshold Enable	2	True	
Run Time (RT)	2	07:42:46	
UL (115)	2	00:00:09	
End Date	2	2/282016	
End Time	2	15:16:10 PM	

Summary Data Panel Pre Noise Cover			
Run Time: 2:27:59	Serial: ESP050011	Model: Edge eg-5	Employee: 1st shift tumbler
Criterion Level: 90 dB	Exchange Rate: 5 dB	Threshold: 90 dB	Weighting: A-weighting
Description	**Meter/Sensor**	**Value**	**Compliance**
Dose	2	69 %	OSHA PEL
Lavg	2	95.8 dB	
Lcpk	2	--	
Pdose (8:00)	2	223.9 %	
PKtime	2	2/9/2016 8:04:58 AM	
TWA	2	87.3 dB	
ProjectedTWA (8:00)	2	95.8 dB	
Criterion Level	2	90 dB	
Weighting	2	A	
Exchange Rate	2	5 dB	
Projection Time	2	480 mins.	
Peak Weighting	2	Z	
Int Threshold Enable	2	True	
Integrating Threshold	2	90 dB	

Summary Data Panel Post Noise Cover			
Run Time: 8:11:14	Serial: ESN020040	Model: Edge eg-5	Employee: 1st shift tumbler
Criterion Level: 90 dB	Exchange Rate: 5 dB	Threshold: 90 dB	Weighting: A-weighting
Description	**Meter/Sensor**	**Value**	**Compliance**
Dose	2	94.4 %	OSHA PEL
Lavg	2	89.4 dB	
Lcpk	2	--	
Pdose (8:00)	2	92.2%	
PKtime	2	2/29/2016 8:07:03 AM	
TWA	2	89.5 dB	
ProjectedTWA (8:00)	2	89.4 dB	
Criterion Level	2	90 dB	
Weighting	2	A	
Exchange Rate	2	5 dB	
Projection Time	2	480 mins.	
Peak Weighting	2	Z	
Int Threshold Enable	2	True	
Integrating Threshold	2	90 dB	

Summary Data Panel Pre Noise Cover			
Run Time: 2:27:59	Serial: ESP050010	Model: Edge eg-5	Employee: Area Sampling 1 (1 foot left of tumbler #2)
Criterion Level: 90 dB	Exchange Rate: 5 dB	Threshold: 90 dB	Weighting: A-weighting
Description	**Meter/Sensor**	**Value**	**Compliance**
Dose	2	201.7 %	OSHA PEL
Lavg	2	95 dB	
Lcpk	2	--	
Pdose (8:00)	2	201.6 %	
PKtime	2	2/8/2016 7:07:26 AM	
TWA	2	95 dB	
ProjectedTWA (8:00)	2	95 dB	
Criterion Level	2	80 dB	
Weighting	2	A	
Exchange Rate	2	5 dB	
Projection Time	2	480 mins.	
Peak Weighting	2	Z	
Int Threshold Enable	2	True	
Integrating Threshold	2	90 dB	
Summary Data Panel Post Noise Cover			
Run Time: 7:44:39	Serial: ESN020040	Model: Edge eg-5	Employee: Area Sampling 1 (1 foot left of tumbler #2)
Criterion Level: 90 dB	Exchange Rate: 5 dB	Threshold: 90 dB	Weighting: A-weighting
Description	**Meter/Sensor**	**Value**	**Compliance**
Dose	2	94.1%	OSHA PEL
Lavg	2	89.8 dB	
Lcpk	2	--	
Pdose (8:00)	2	97.3 %	
PKtime	2	2/28/2016 10:17:45 AM	
TWA	2	89.5 dB	
ProjectedTWA (8:00)	2	89.8 dB	
Criterion Level	2	90 dB	
Weighting	2	A	
Exchange Rate	2	5 dB	
Projection Time	2	480 mins.	
Peak Weighting	2	Z	
Int Threshold Enable	2	True	
Integrating Threshold	2	90 dB	

Summary Data Panel Pre Noise Cover			
Run Time: 8:00:06	Serial: ESP050011	Model: Edge eg-5	Employee: Area Sampling 2 (1 foot right of tumbler #2)
Criterion Level: 90 dB	Exchange Rate: 5 dB	Threshold: 90 dB	Weighting: A-weighting
Description	**Meter/Sensor**	**Value**	**Compliance**
Dose	2	141.1 %	OSHA PEL
Lavg	2	92.4 dB	
Lcpk	2	--	
Pdose (8:00)	2	141 %	
PKtime	2	2/8/2016 6:57:39 AM	
TWA	2	92.4 dB	
ProjectedTWA (8:00)	2	92.4 dB	
Criterion Level	2	80 dB	
Weighting	2	A	
Exchange Rate	2	5 dB	
Projection Time	2	480 mins.	
Peak Weighting	2	Z	
Int Threshold Enable	2	True	
Integrating Threshold	2	80 dB	

Summary Data Panel Post Noise Cover			
Run Time: 8:11:38	Serial: ESL010390	Model: Edge eg-5	Employee: Area Sampling 2 (1 foot right of tumbler #2)
Criterion Level: 90 dB	Exchange Rate: 5 dB	Threshold: 90 dB	Weighting: A-weighting
Description	**Meter/Sensor**	**Value**	**Compliance**
Dose	2	81.3 %	OSHA PEL
Lavg	2	88.3 dB	
Lcpk	2	--	
Pdose (8:00)	2	79.4 %	
PKtime	2	2/28/2016 8:08:15 AM	
TWA	2	88.5 dB	
ProjectedTWA (8:00)	2	88.3 dB	
Criterion Level	2	90 dB	
Weighting	2	A	
Exchange Rate	2	5 dB	
Projection Time	2	480 mins.	
Peak Weighting	2	Z	
Int Threshold Enable	2	True	
Integrating Threshold	2	90 dB	